DISCRIMINATING CLEAR SKY FROM CLOUD WITH MODIS

Steve Ackerman
Chris Moeller
Kathleen Strabala
Cooperative Institute for Meteorological Satellite Studies
University of Wisconsin - Madison
Madison, WI

Brian Baum
NASA/LaRC
Hampton, VA

Ron Welch
Institute of Atmospheric Sciences
South Dakota School of Mines and Technology
Rapid City, SD

Paul Menzel
NOAA/NESDIS
University of Wisconsin - Madison
Madison, WI

Outline of Presentation

* Definition of MODIS Cloud Mask

* Features of Cloud Detection

* Heritage of Cloud Algorithms

* Components of the MODIS Cloud Algorithm

  - IR Threshold
    - histogram
    - temporal continuity
    - moisture correction
    - scene uniformity

  - Reflectance
    - examples from MAS

  - Non surface viewing spectral bands
    - 1.38 um near IR cirrus detection
    - 13.9 um discrimination of high cloud
    - 6.7 um help in the polar regions

  - Vis/IR Multispectral Approaches

* Inputs and Outputs

* Summary

Definition of MODIS Cloud Mask

* will indicate whether FOV has an unobstructed view of the earth surface

* will try to indicate whether clear FOV is affected by cloud shadows

* will be generated at the three resolutions of the MODIS data
  (250 meter, 500 meter, and 1000 meter)

* input is assumed to be calibrated and navigated level 1B data

* cloud mask will be determined for good data only
  (ie. FOVs where ch 1, 2, 6, 8, 19, 22, 26, 27, 29,
  31, 32, and 35 have radiometric integrity)

* incomplete or bad data will create holes in the cloud mask.

General Features of Cloud Detection

* generally characterized by higher reflectance and lower temperature than the underlying earth surface

* simple visible and infrared window threshold approaches offer considerable skill in cloud detection

* there are many surface conditions when this characterization of clouds is inappropriate, most notably over snow and ice

* some cloud types such as cirrus, low stratus, and small cumulus are difficult to detect because their radiances do not contrast sufficiently with that from the surface below.

* cloud edges cause further difficulty since the MODIS FOV is not completely cloud nor clear

* spatial coherence tests offer confirmation scene uniformity

* multispectral approaches mitigate many single band deficiencies

MODIS Cloud Mask will benefit from previous work

* ISCCP (International Satellite Cloud Climatology Project)
  Rossow (1989, 1993), Rossow et al. (1989) and Seze and Rossow (1991)
  VIS/IRW band thresholds from leo and geo clear-sky composite

* CLAVR (Cloud AVHRR algorithm)
  Stowe et al.(1994)
  five VIS/IR bands for 2 x 2 GAC data in spectral and spatial tests

* CO_2 Slicing
  Wylie et al. (1994)
  CO_2 bands characterize thin cirrus

* Spatial Coherence
  Coakley and Bretherton (1982)
  standard deviation versus mean radiance produces arches

MODIS Cloud Mask will have considerable advantage

* it has multispectral information and high spatial resolution

* 12 VIS and IR bands will be used to mitigate difficulties
  at 5 km x 5 km scale

Components of MODIS Cloud Algorithm

Reflectance Uniformity Test

max and min values close indicate cloud free scene uniformity
$r_{.66}$ over land and $r_{.87}$ over ocean

daytime only, must be ecosystem specific
must account for satellite zenith and view angle

Reflectance Ratio Test

$r_{.87}/r_{.66}$ is between 0.9 and 1.1 for cloudy regions
if true then further tests should be performed to test for cloud

must be ecosystem specific

Reflectance Threshold Test

$r_{3.9} > 6\%$ considered to be cloudy and $< 3\%$ considered to be snow/ice

problems in bright deserts

Infrared Window Brightness Temperature Threshold and Difference Tests

$BT_{11} < 270$
$BT_{11} + a_{PW} * (BT_{11} - BT_{12}) < SST$
$BT_{11} + b_{PW} * (BT_{11} - BT_{8.6}) < SST$

where a_{PW} and b_{PW} are determined from a lookup table as a function of total precipitable water vapor (PW).

$BT_{3.9} - BT_{11} > 3$ indicates presence of partial of thin cloud cover

$BT_{11} - BT_{6.7}$ show large negative difference for clear sky over the Antarctic Plateau winter

IR threshold and difference tests sensitive to surface emissivity and atmospheric PW, dust, and aerosols

Infrared Window One-Dimensional Histogram Tests

$BT_{thres} = BT_{max}$ - sigma

need surface uniformity

Near IR Thin Cirrus Test

r1.38 > threshold indicates presence of thin cirrus cloud

ambiguity of high thin versus low thick cloud (resolved with $BT_{13.9}$)
problems in high terrain

CO_2 Channel Test for High Clouds

$BT_{13.9}$ < threshold

possible problems in high terrain

Infrared Window Radiance Spatial Uniformity
Infrared Window plus Visible Threshold Tests
Two-Dimensional Infared and Visible Histogram Analysis

best over oceans, must be characterized by ecosystem

Detection of Cloud Shadows

difficult

Automated Classification Methods

tied to quality flag, uses texture tests

Inputs

* sun angle, azimuthal angle, and viewing angle

* land/water map at 1 km resolution
  (MODIS will develop a better one subsequently)

* topography at 10 minute resolution
  (Navy character map will provide this;
  as well as rugged versus plateau terrain)

* ecosystems at 10 minute resolution
  (map of 59 classes of ecosystems available)

* snow/ice from yesterday known at 1 km resolution
  (ancillary sea versus land discrimination at 18 km res)

* surface temperatures (sea and land) at 1 degree resolution
  (NMC analysis or yesterdays MODIS observations)

Channels used in generation of MODIS Cloud Mask

Channel Number	Wavelength (microns)	Used in Cloud Mask (B indicates backup to another channel)
Reflected radiation		
1	0.659	Y
2	0.865	Y
3	0.470	N
4	0.555	B
5	1.240	N
6	1.640	Y
7	2.130	N
8	0.415	Y
9	0.443	N
10	0.490	N
11	0.531	N
12	0.565	N
13	0.653	N
14	0.681	N
15	0.750	N
16	0.865	N
17	0.905	N
18	0.936	N
19	0.940	Y?
26	1.375	Y
20, 21	3.750	B
22	3.959	Y
23	4.050	N
24	4.465	N
25	4.515	B
Emitted radiation		
20, 21	3.750	B
22	3.959	Y
23	4.050	N
24	4.465	N
25	4.515	B
27	6.715	Y
28	7.325	N?
29	8.550	Y
30	9.730	N
31	11.030	Y
32	12.020	Y
33	13.335	N
34	13.635	N
35	13.935	Y
36	14.235	N

Outputs (24 bit word for each FOV)

bit	content
	summary of all algorithms
1	obstructed fov (yes/no)
2	quality flag
	ancillary information
1	snow/ice
2	land/water
1	sunglint found (yes/no)
	results from classes of cloud algorithms
1	IR threshold found cloud
1	IR temperature differences found cloud
1	vis threshold found cloud
1	vis ratio found cloud
1	near IR thin cirrus test found cloud
1	CO2 high cloud test found cloud
1	IR spatial tests found cloud
1	vis spatial tests found cloud
1	multiple layers identified
1	cloud shadow found
1	1.6 found cloud
	room for additional information
6	spare

Summary

* MODIS Cloud Mask indicates if FOV has unobstructed view of earth surface

* Collaboration with members of CERES Science Team

* Heritage algorithms incorporated (ISSCP, CLAVR, CO2, the golden arches)

* Initially conservative approach will be adopted (if any test is positive, mask will indicate obstructed FOV)

* Multispectral approaches will alleviate single band deficiencies

* Prelaunch testing with HIRS/AVHRR and MAS data

* Ecosystem specific algorithms will be developed

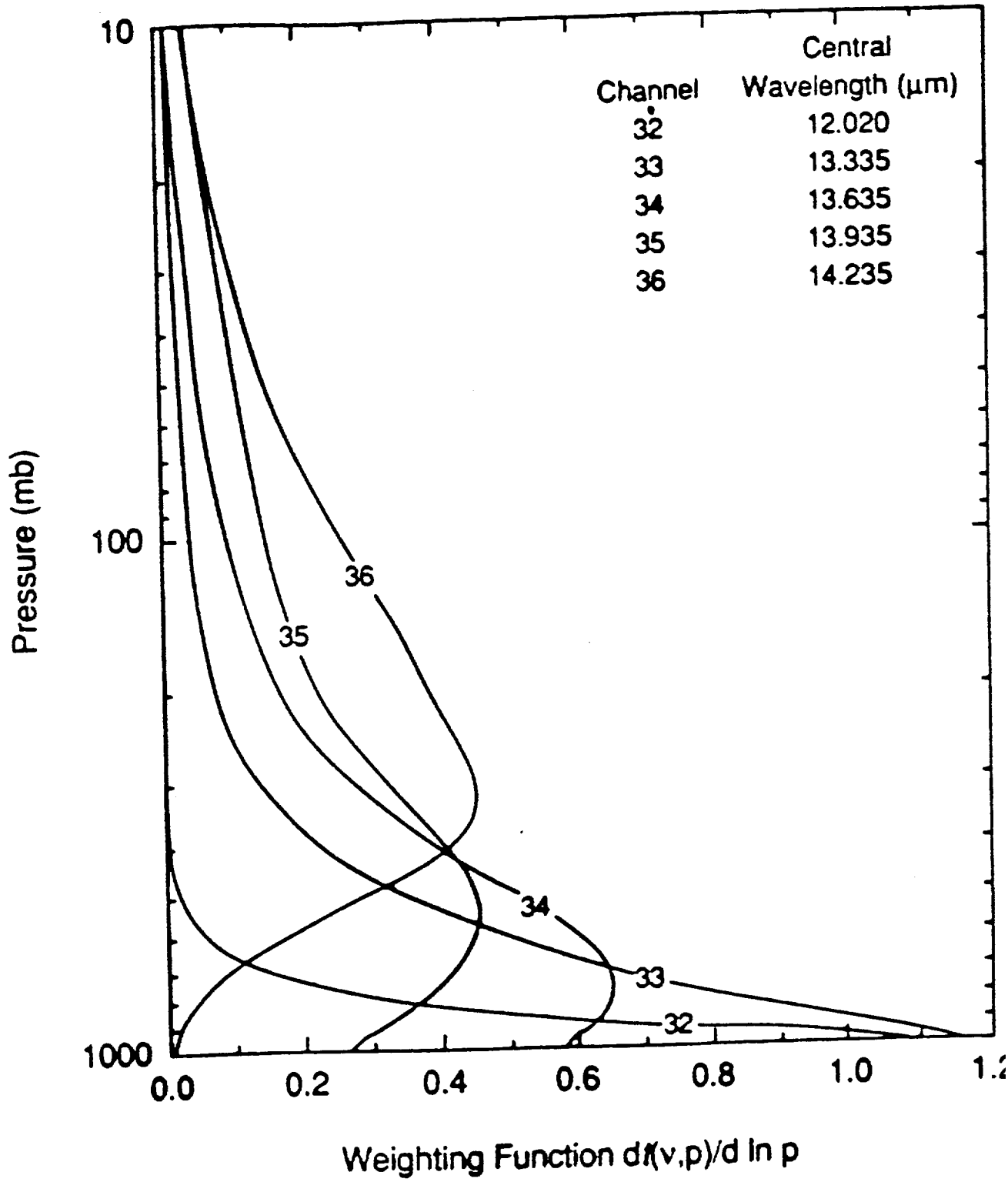

10
100
1000
Pressure (mb)
0.0
0.2
0.4
0.6
0.8
1.0
Weighting Function df(v,p)/d ln p
Channel
Central Wavelength (μm)
32 12.020
33 13.335
34 13.635
35 13.935
36 14.235
36
35
34
33
32

Figure 1

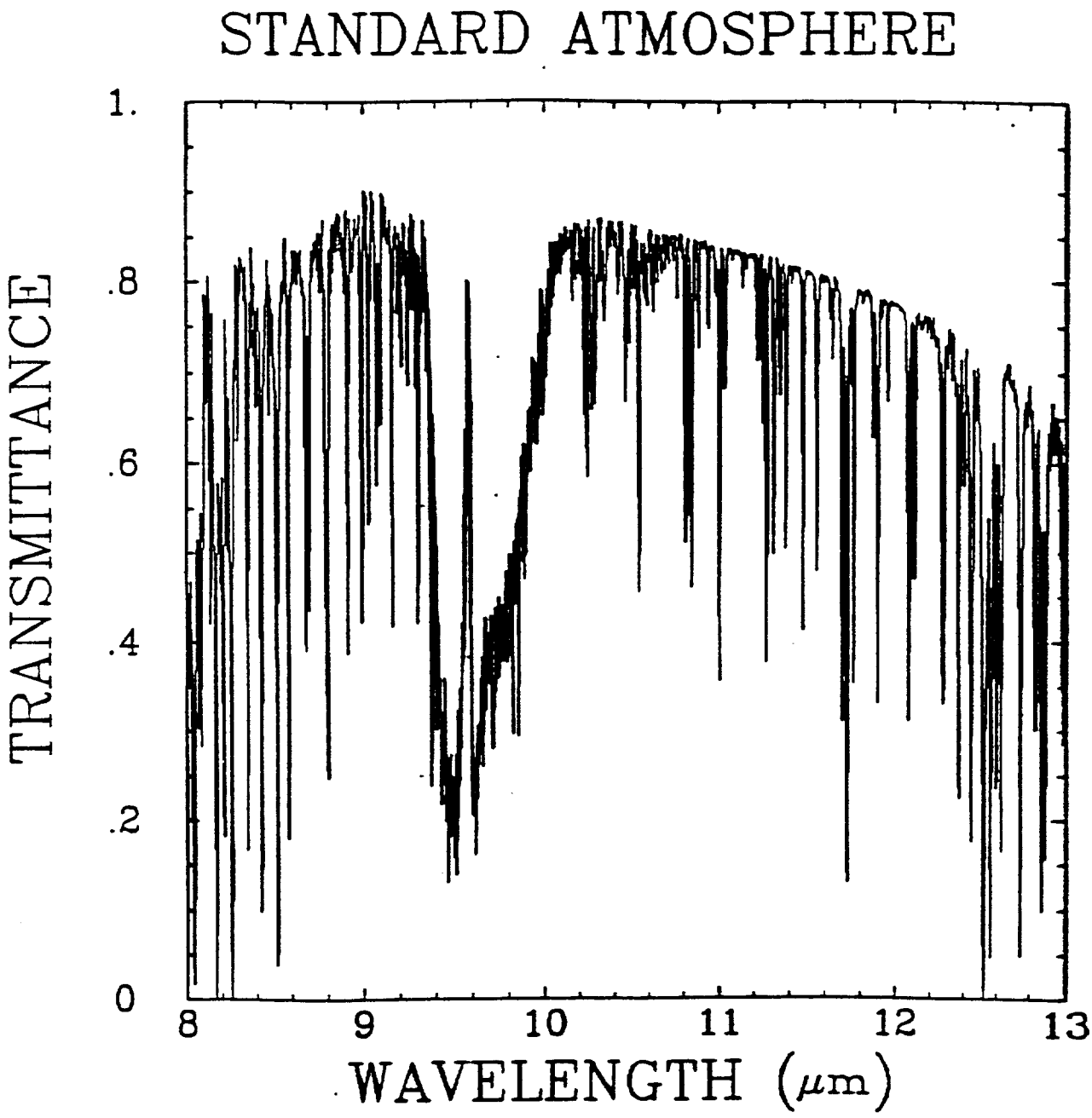
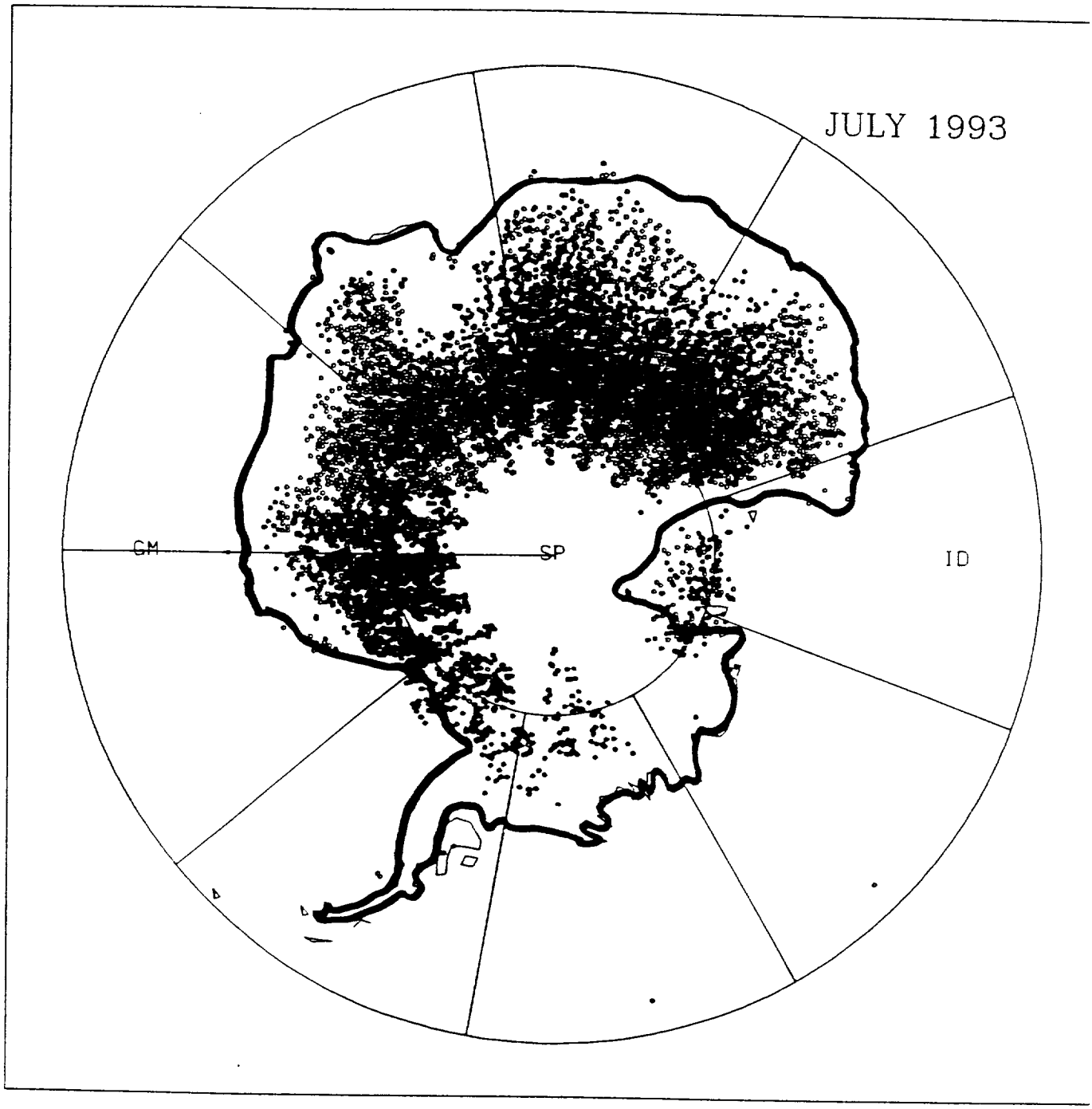


Figure 2. HIS (High resolution Interferometer Sounder) total transmittance spectra for a standard atmosphere across the 8-13μm window.


JULY 1993
GM
SP
ID

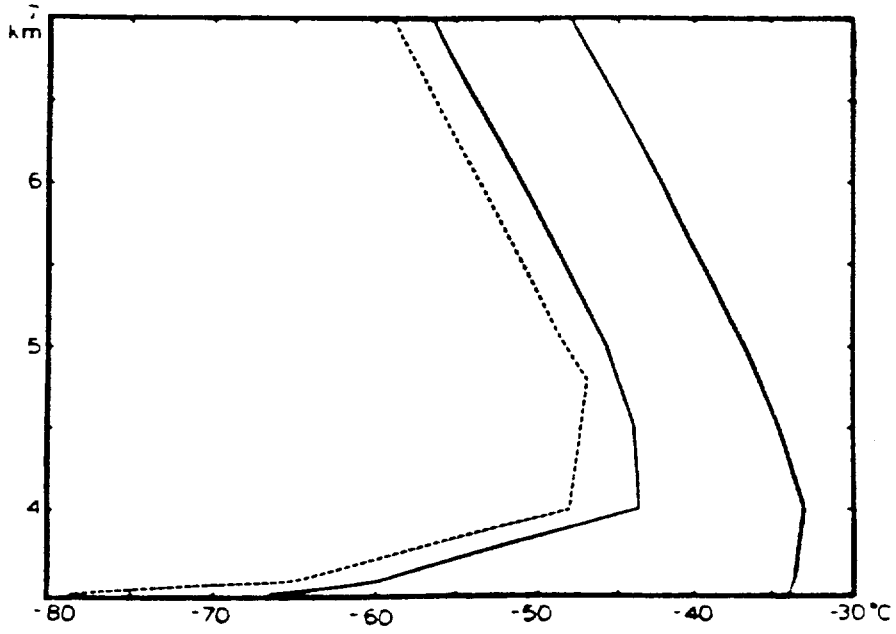
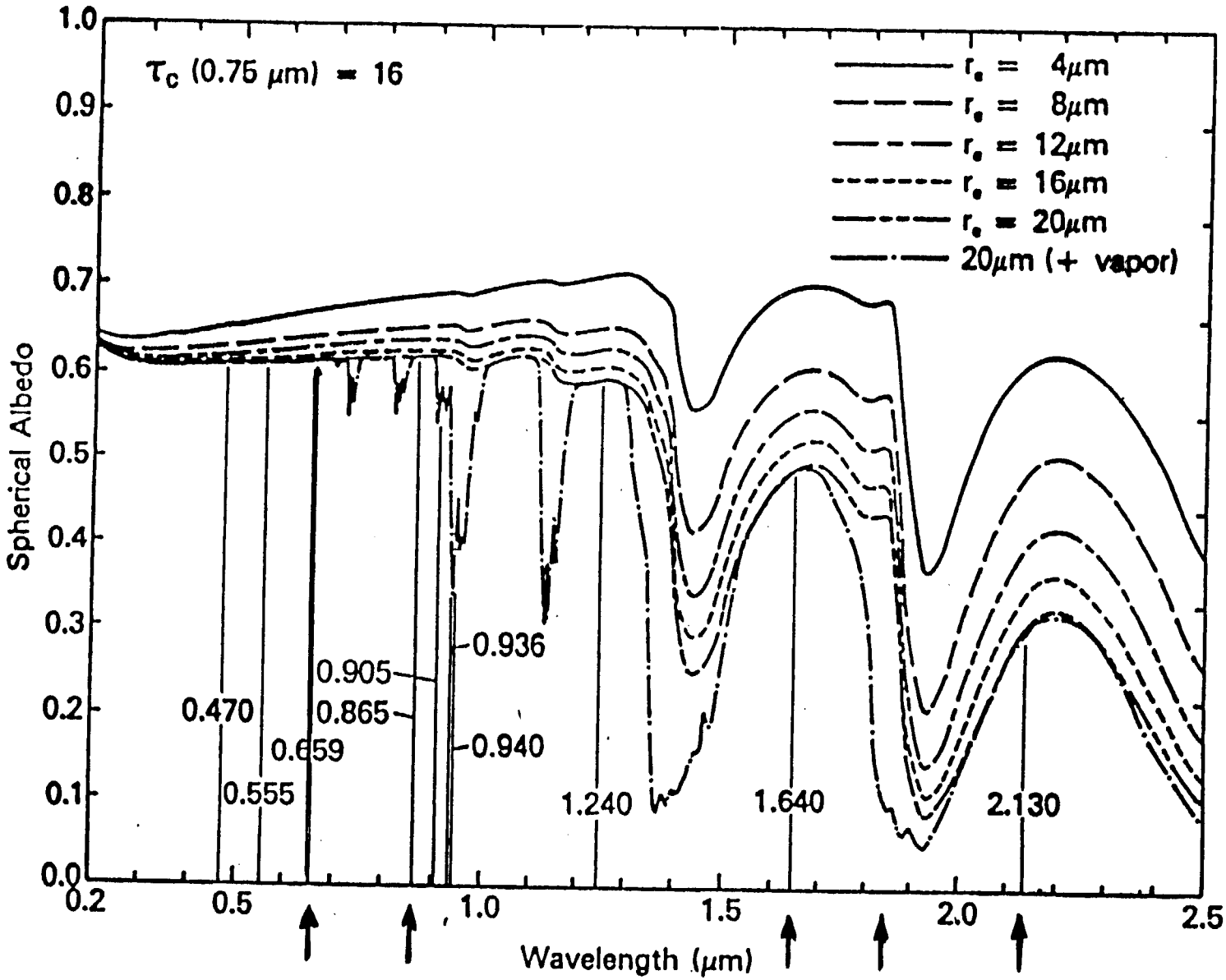
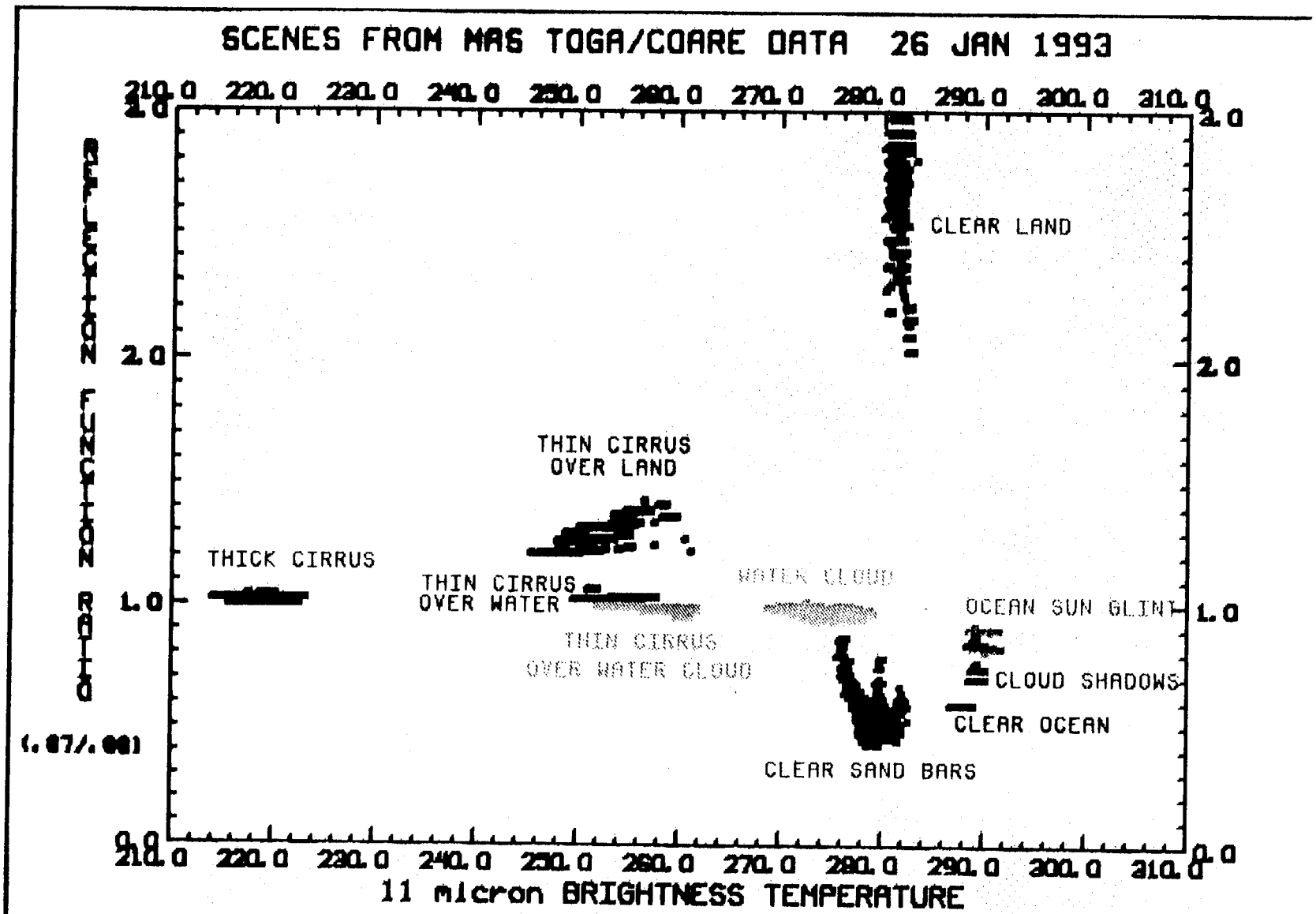
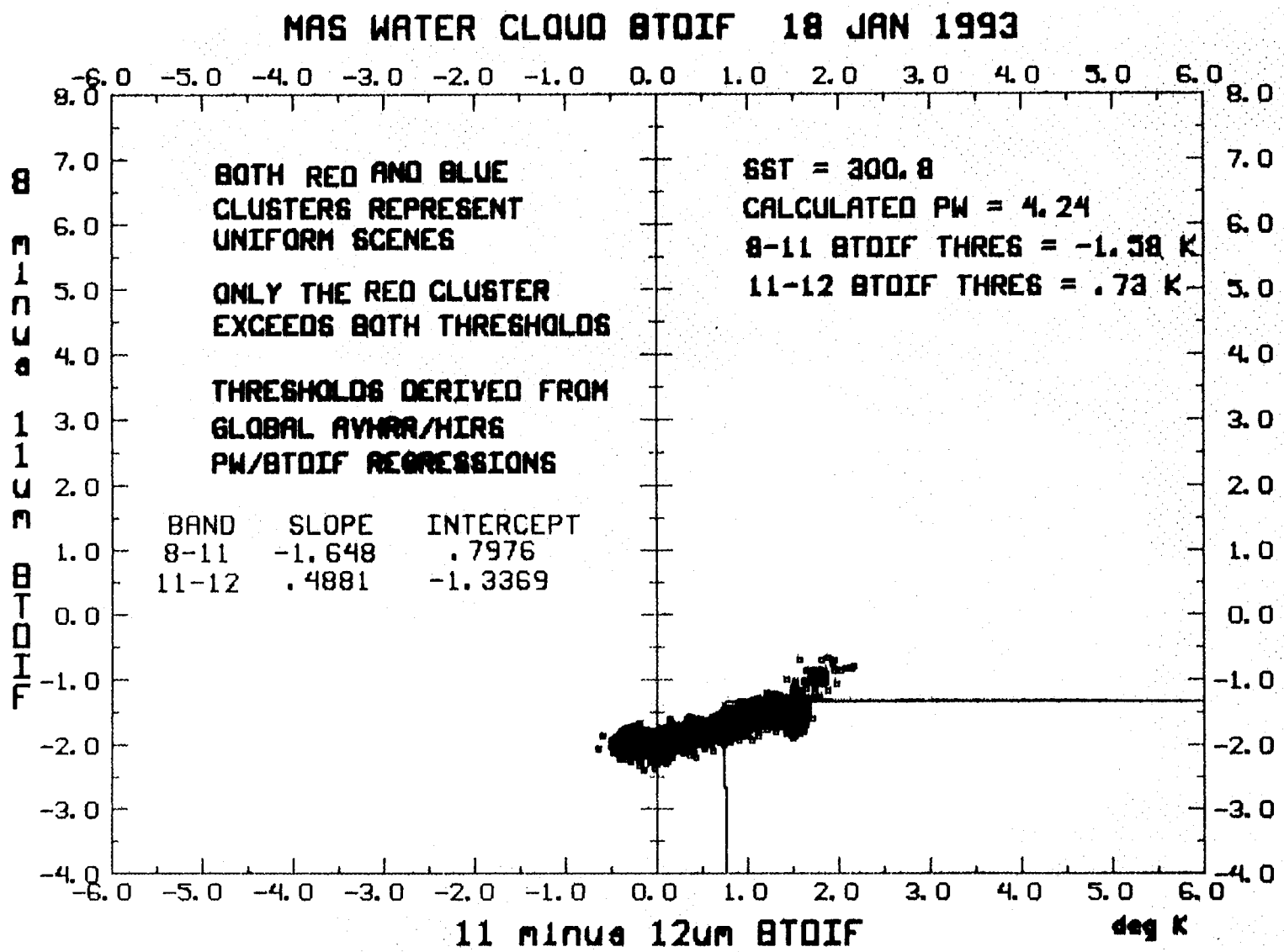
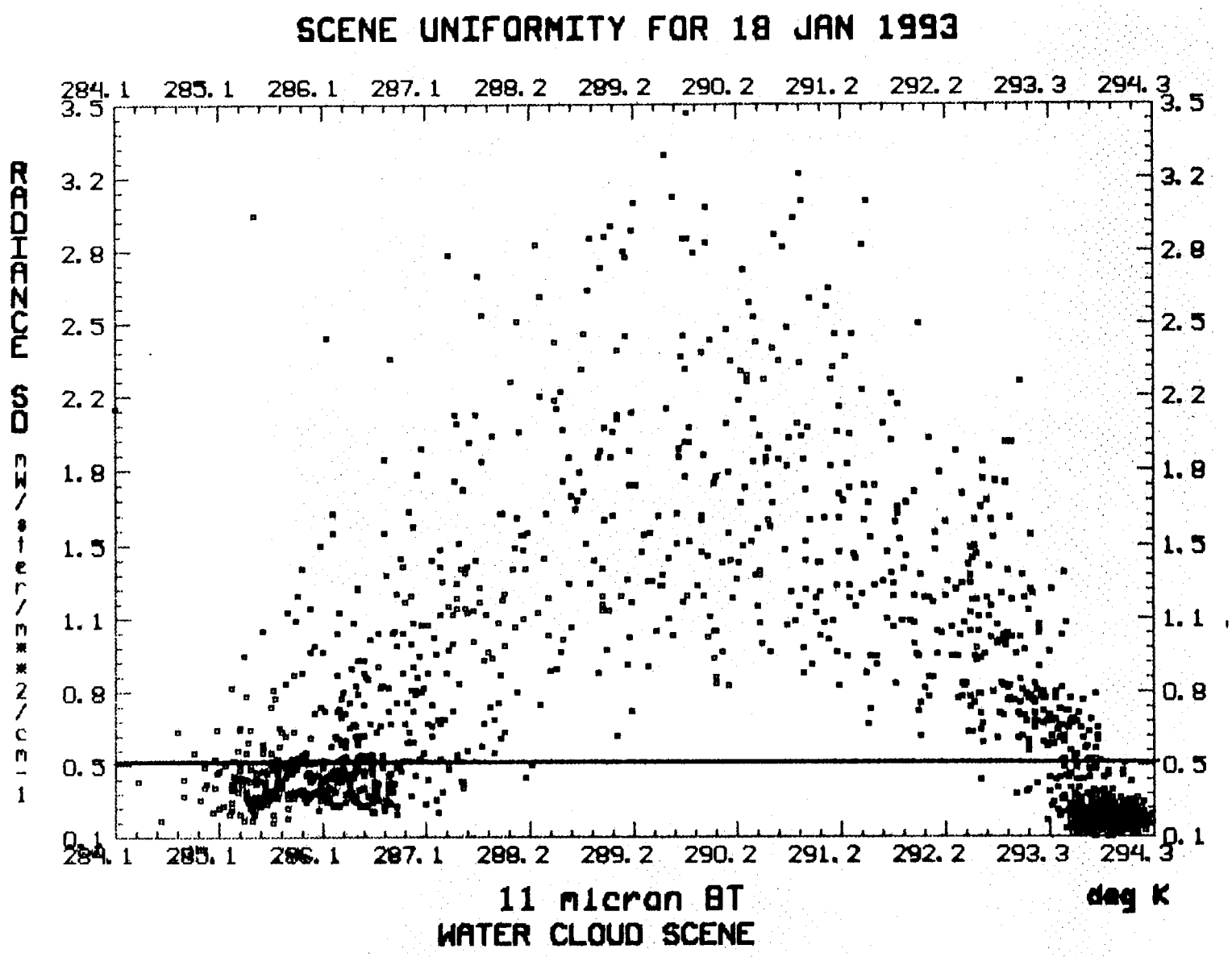


Figure 3.8: Vostok (3488 m). Average temperature between the surface and 7000 meters above sea level in summer (December and January) and winter (April-September). Also included is an example of an extremely strong inversion on June 2, 1960 (from Schwerdtfeger, [1970]).


τ_c (0.75 μm) = 16
r_e = 4μm
r_e = 8μm
r_e = 12μm
r_e = 16μm
r_e = 20μm
20μm (+ vapor)
Spherical Albedo
Wavelength (μm)
0.470
0.555
0.659
0.865
0.905
0.936
0.940
1.240
1.640
2.130
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0.2
0.5
1.0
1.5
2.0
2.5


SCENES FROM MAS TOGA/COARE DATA 26 JAN 1993
210.0 220.0 230.0 240.0 250.0 260.0 270.0 280.0 290.0 300.0 310.0
2.0
1.0
0.0
CLEAR LAND
THIN CIRRUS
OVER LAND
THICK CIRRUS
THIN CIRRUS
OVER WATER
WATER CLOUD
OCEAN SUN GLINT
THIN CIRRUS
OVER WATER CLOUD
CLOUD SHADOWS
CLEAR OCEAN
CLEAR SAND BARS
11 micron BRIGHTNESS TEMPERATURE


MAS WATER CLOUD BTDIF 18 JAN 1993
BOTH RED AND BLUE
CLUSTERS REPRESENT
UNIFORM SCENES
ONLY THE RED CLUSTER
EXCEEDS BOTH THRESHOLDS
THRESHOLDS DERIVED FROM
GLOBAL AVHRR/HIRS
PW/BTDIF REGRESSIONS
BAND SLOPE INTERCEPT
8-11 -1.648 .7976
11-12 .4881 -1.3369
SST = 300.8
CALCULATED PW = 4.24
8-11 BTDIF THRES = -1.38 K
11-12 BTDIF THRES = .73 K
8 minus 11um BTDIF
11 minus 12um BTDIF
deg K


SCENE UNIFORMITY FOR 18 JAN 1993
RADIANCE SD MW/ster/cm**2/cm-1
284.1 285.1 286.1 287.1 288.2 289.2 290.2 291.2 292.2 293.3 294.3
3.5 3.2 2.8 2.5 2.2 1.8 1.5 1.1 0.8 0.5 0.1
11 micron BT
deg K
WATER CLOUD SCENE

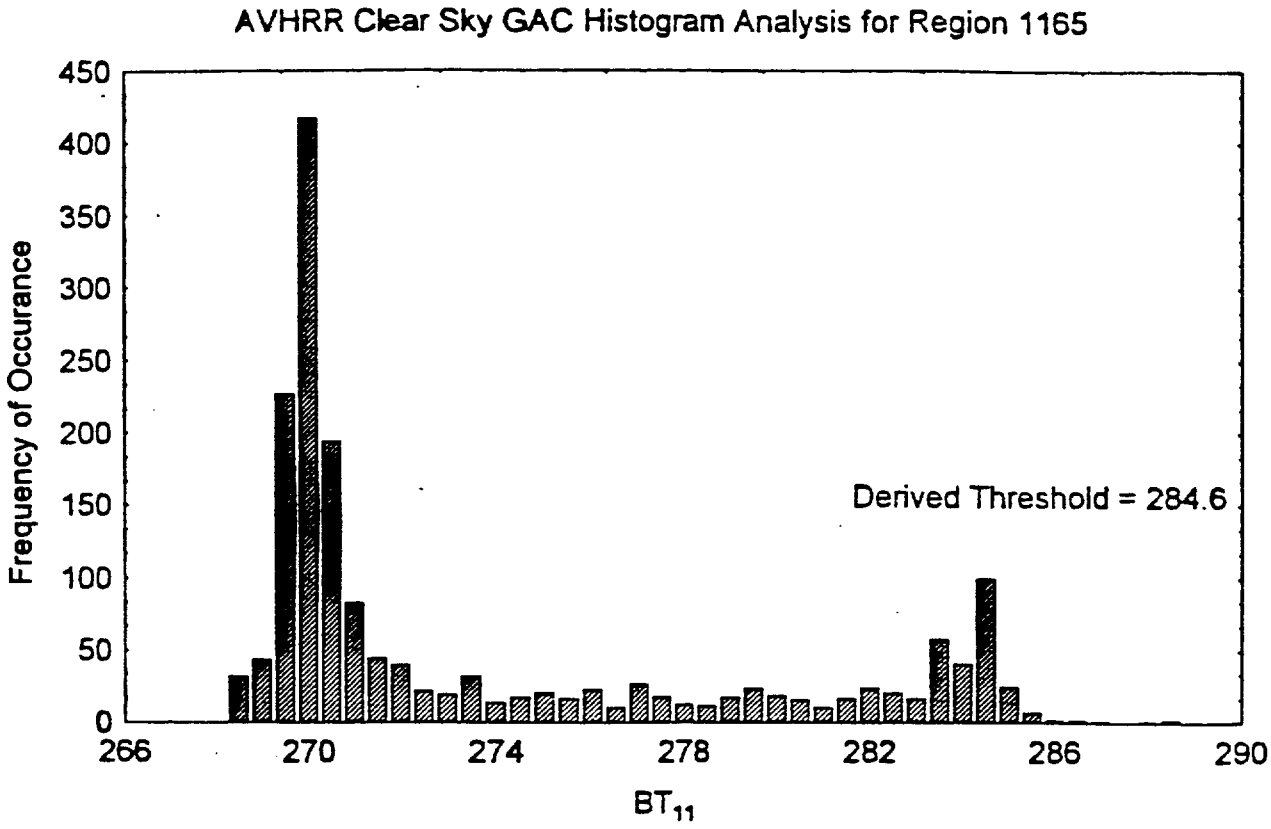
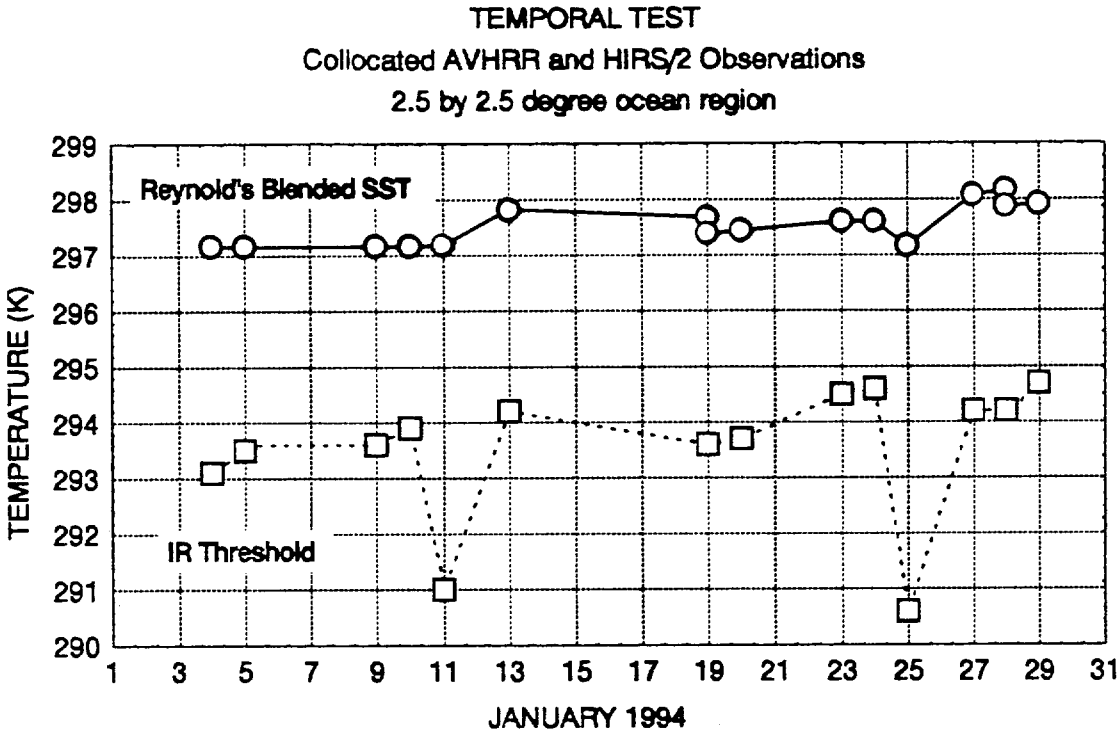


Figure 6. Example of infrared histogram analysis technique using AVHRR GAC data for a 2.5° x 2.5° ocean region. The derived clear-sky BT_{11} threshold is 284.6 K.


TEMPORAL TEST
Collocated AVHRR and HIRS/2 Observations
2.5 by 2.5 degree ocean region
Reynold's Blended SST
IR Threshold
TEMPERATURE (K)
299
298
297
296
295
294
293
292
291
290
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
JANUARY 1994